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PRESENT DEVELOPMENT AND CURRENT PROBLEMS ABOUT COMPOSITE IN OUR COUNTRY

by

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PRESENT DEVELOPMENT AND CURRENT PROBLEMS ABOUT COMPOSITE IN OUR COUNTRY

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(photo)

Born in Shanghai in 1928, graduated from Civil Engineering Department in Shanghai San Johns University in 1950, admitted into graduate program in Harbin Institute of Technology in August 1950, graduated and employed as a professor in Harbin Institute of Technology in 1953. Started research on composite since 1979, currently working as a professor, PhD thesis adviser and chairman of composite research section in Harbin Institute of Technology. Also a member of International Committee of Composite, member of editorial board of << Acta Solid State Mechanica >> and << Acta Compound Matarial >>, published book << Mechanics of Short Fibre Composite >> and related papers in the amount of more than 40.

Abstract: This paper summarizes 10 problems in common concern of current composite industry from 250 papers of ICCM VI: development of composite into high temperature material, cost of composite in civil use, fibre, development of polymer basegroup, interface study, processing technique, damageless flaw detection, mechanical characteristics of composite, structural analysis and interlayer stress calculation, etc. Finally, it puts forward several principal points about composite development in our country.

Key words: High temperature composite, Constituent material, Interface, Damageless flaw detection, Characteristics of composite, Translations, China, Chinese Language. (KR)

I. Current Development of Composite

People have cleared their mind of doubt about composite and started to think of using it in various industrial areas since 1969. Within last two decades the competition situation put it at the significant point on stage. Figure 1 shows the principal research projects in developing composite during these years. Armanent race and opening up outer space set new requirements on material. Composite is of temporary advantage due to its inherent merits (high specific strength, high specific stiffness, flexible design, etc) while metal material, such as ultralight aluminium-lithium alloy material is also attractive. Therefore, it becomes necessary to solve the problem about heat resistance of composite. In the competition in civil industry, especially in international car markets, composite is considered to be a prospective material, but its cost problem has to be solved before it can be used for human being. We want furthermore to mention that Figure 1 lists just roughly the problem of current concern about composite, in fact composite used for civil industry is also faced with heat resistance problem. Military industry and opening up outer space also have cost problem, especially large amount of problems in using composite has to be solved. For example, lots of research work are necessary for solving problems in toughness of epoxy-group composite and layer-off, damate, etc.

1.1 Armanent race and opening up outer space force composite to develop into heat resistance material

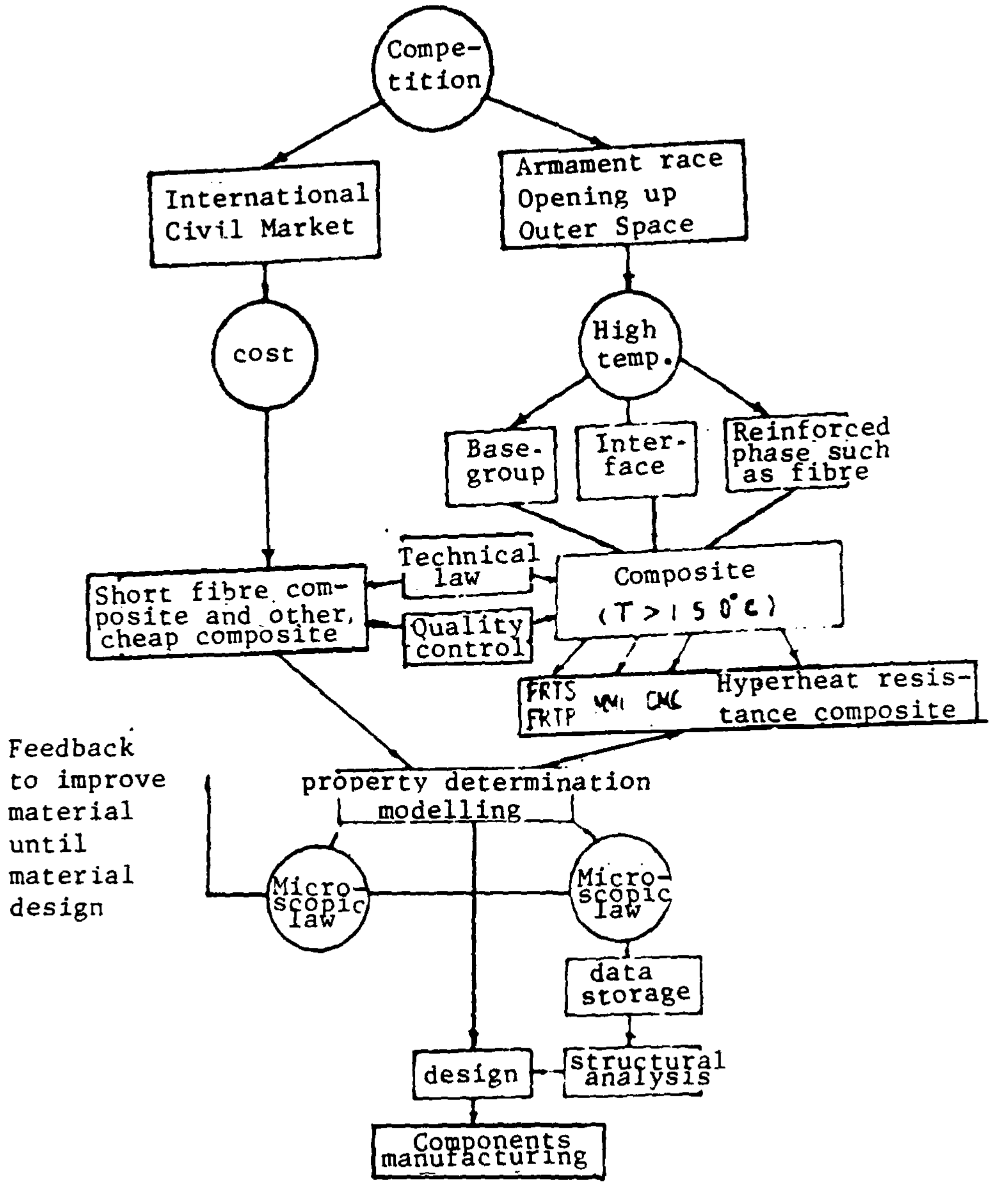

Figure 1 Research projects of composite

The people in Aeritalia, Aerospatiale, British and Messerchimidt MB-ERNO had a very confidential meeting in Rome, Europe, where they discussed the plan of developing Space-plane which has the flight height of 30 kilometers and the flight speed of 5,000 kilometers/hour and 150 seats inside each plane. Such a plane takes only 1 hour to fly from London to Sydney compared to 14-15 hours needed by an ordinary plane. The United States of America have actually planned to make this kind of space plane __ "Oriental Train" due to State of the Union Message by the US President Reagan. The reason to call it "Oriental Train" is that it takes less than two hours to reach Asia from western coast in US.

In the middle of the next decade US will develop "Advanced Tactical Flighter Plane" (ATF) which will fly at superspeed with larger effective load and overload of 9g while making turn. Its computer-controlled adjustment at flight is as frequent as a dozen per second while the total weight of the plane is less than 5 thousand pounds. In 1990 Lockheed-Californio and Northrop will develop two types of sample plane with the weight being 17-18% less than that of current flighter plane. The landing gear components must be made of metal, so the other components are considered for reducing weight. It is assumed that nearly half of the plane components will use composite and much of them will no longer be the traditional epoxy-group composite because aerodynamic heating denatures epoxy resin.

Other weapons and space flighter also have heat resistance problem. For example, satellite needs increase its effective load in order to carry more devices for experiments. The temperature difference between the side exposed to the Sun and the opposite shade side may be as much as several hundred degrees. Therefore, some components originally made of metal such as folded antenna, solar sailboard, laser mirror, X- ray telescope, have to use composite instead. Material for heatproof film on missile and some components of engine also need use metal-group or ceramic-group composite. Besides, armoured plate, caterpillar tread and barrel of tank and naval vessels also need to use heat resistance composite.

Heat resistance means withstanding temperature higher than the working temperature of epoxy resin, in other words, any composite with its working temperature being higher than 150°C is called heat resistance composite. Working temperature of composite generally depends on its basegroup, but fibre itself has its limit of heat-resistance. For example, the strength of aromatic polyfibre may get deteriorated at 150°C for long time. At the temperature above 300°C glass fibre may get humidified. Carbon fibre can withstand higher temperature, but at too high temperature it may get oxidized. From resin group the ones which may usually be used as heat resistance polymer are:

Thermo-reinforced resin: Reprocessed epoxy can withstand 180°C, phenolic and BMI can withstand 250°C, PSP and amilan can withstand 300°C (the higher temperature the more brittle). Thermoplastic resin: Crystal thermoplastic polymer has Tg=210°C while amorphous thermoplastic polymer has Tg=260°C. Considering the pressure material has to withstand, the maximum working temperature is about Tg--30°C. APC(HTX) of ICI (a type of PEEK) can work at 350°C provided its stiffness can be reduced by 50%. At higher temperature metal-group composite becomes necessary. Nowadays people are most interested in aluminium-magnesium alloy at the temperature below 500°C and titanium-basegroup at 600°C to 700°C. The technique in boron/aluminium is relatively mature but it costs too much. Silit metal-group composite is developing. Aluminium, magnesium and titanium are prospective basegroup of metal-group composite for making low-cost SiC, Si_3N_4 crystalline multifibre, such as Nicalon, Tyrano and aluminium-oxide crystalline multifibre, fabric, film. The problem is that the technique of metal-group composite requires guaranteed quality of its interface as well as low cost for market competition. At higher temperature glass or ceramic-glass are necessary to be used as the basegroup. Nowadays Nicalon SiC is used to reinforce ceramic at the temperature region of

300 to 450°C in the competition with MMC (metal-group composite). The composite reinforced by SiC and other ceramic fiber-reinforced ceramic-glass fibre can work between 900°C to 1100°C to 1200°C. They are prospective in wide application to engine. There are diverse manufacturing engineering for people to select in application, but so far suspension liquid soaking seems to be the most successful technical process. Adding glass and ceramic powder into organic colloid and making presoaking ribbon from fiber with glass-ceramic powder followed by pressing ribbon into components at the temperature of1200°C and under the pressure of 6MPa. The purpose of 1200°C is to burn out colloid. Fibre damage should be avoided. Select basegroup with the thermal expansion coefficient close to that of fibre to prevent from causing crackles due to too much thermal stress. Interface sticking remains a problem for further investigation.

The main role of ceramic-group composite (CMC) is to increase toughness of ceramic-group which differs from enhancing strength and stiffness using resin-group composite. In 1979 low-cost ceramic crystalline beard and ceramic fiber came out and the research on that CMC has been developing most rapidly in these years.

Superheat-resistance material is necessary at the temperature above 1200°C. Fibre oxidization or creep may happen. Carbon carbonide is a superheat-resistance composite which can work at the temperature above 2000°C provided oxidization is avoided. Without protection against oxidization its working temperature is 500°C only. For that simply coat it by antioxident such as Al_2O_3, SiO_3 or Cr_2O_3. Without such protection carbon carbonide can be used for a short time such as breaking wheel in flighter plane, nozzle throat bush of racket engine or nose cone of missile.

There are totally 8 papers are grouped with the subject of ceramic-group composite at this meeting from which 4 papers study mechanism of facilitating increase of toughness using fibre-reinforced ceramic. For example, Nicalon-reinforced silicon oxide becomes degummed at fibre/basegroup interface. SiC/lithium aluminosilicate and GR/boronsilicate glass frictionize at interface in case of either static-loaded or bumped. Some people worry that fibre-reinforced ceramic separates material resulting in enhancing mechanism of energy consume while others worry that natural microcrackle may expand causing deflection of strike also resulting in extra energy consume. The rest 4 papers discuss about fibre-reinforced concrete. Indian authors recommend reinforcing concrete by natural plant fibre. One paper from them suggests making wavy brick using sisal hemp instead of cancerogenic asbestos.

There are totally 37 papers in the group with the subject of metal-group composite. From them 20 papers are related to manufacturing engineering, interface microstructure and flaw mechanism while the rest 17 papers discuss mainly macroscopic property and components forming of loaded MCC under different conditions.

Original "Solidification Processing Group" of MIT has now developed into "Solidification and Metal-group Composite Research Group" attached to Research Center of Manufacture Engineering and Property Assessment of Metal-group Composite". Research in that group includes Pressure Infiltration, Semi-solid slurry processing, compocasting, Ccmposite Solidification, Interface science and tailoring, microstructural design of basegroup and improvement of physical mechanical property of metal-group composite. The paper reports their research in MIT. Another paper summarizes microstructural characteristics inside MMC made by melt osmosis and powder metallurgy. There is another paper discussing about the speed of molten aluminium osmosizing into preheated aluminium oxide "SAFFIL" fibre preform during pressure casting. There are 12 papers discussing about SiC crystalline bread or short fibre of MCC. They indicate that material prepared by compositive casting, extrusion casting and drawing shows higher stiffness, hardness and toughness but lower ductility and breaking power and the relation between them and processing parameters. There is one paper reporting research in SiC/Al flow change behavior. Japanese use vacuum system for extrusion casting resulting in raising MCC strength by 6% at the same time also raising its reliability. Manufacture of aluminium oxide fibre is easy to be managed so its crystal microstructure can be changed in order to obtain desired strength, stiffness and specific gravity. There is one paper introducing preparation of arc short fibre and making MMC engine components using drawing forming technique. It needs to control chamical reaction at its interface.

Macroscopic property of MMC under different conditions includes effects of thermal cycle, fatigue, high strain rate, creep, nuclear radiation, superplasticity, aging, hardening, etc. The paper about hygrothermal effect of carbon-graphite/aluminium by Wu Renjie in our country is one of them.

Our country has contributed 4 more papers to metal-group composite which are break behavior of C/Pb-Sn and C/Zn, high temperature inclusion of C fibre with its surface coated by Cu and Ni (by Hefei Institute of Technology), study on HIP C/Al interface and break (by Shenyang Metal Institute).

1.2 The key for developing composite in civil industry use is the cost problem, therefore large-scale application and production are necessary.

The Scala Lecture at this meeting is "Large-scale production of composite" given by Jardon from French Reno Car Manufactory. He said that the application of composite to industry is characteristic of "high quality/small-quantity production" mainly due to concern about its cost.

Any product contains three parts of cost: (1) manufacturing cost, that is the cost at buying it, (2) cost in using that product, (3) cost due to abnormal damage of product, for example, abnormal damage for plane means plane destruction and human death, while for space flighter (such as satellite) it means destruction of flighter with all the experimental equipments in it. Destruction of weapons may result in defeat, but it is difficult to estimate its political and financial loss. These three cost parts result in the production principle of high quality/small-quantity.

Things are different in civil industry. For example, in car manufacture only the first part, manufacturing cost, is crucial though everyday gase consume is also an index in market competition. Table 1 compares manufacturing cost of car, plane and space flighter. From that it can be realized, that civil industry can not follow the

Table 1 Comparison of manufacturing cost

car, plane or space flighter	R9	Airbus	Ariane 2
manufacturing cost (US$ 1,000)	10	60,000	50,000
weight	850	83,000	30,000
manufacturing cost per kilogram	12	720	165

production principle of high quality/small-quantity, otherwise nobody can afford composite. Nowadays car industry usually yields 4,000 to 5,000 cars for a same type daily while productivity of plane and space flighter is much less, for example, heliscoper has the relatively high productivity of 600 yearly. Therefore, the application of composite to civil industry must be in large-stage production and reduce its manufacturing cost by automation and large-stage. Civil industry uses composite with cheapest fiber and basegroup, such as short cut glass-fibre and polyester usually filled with costless stuffing.

Nowadays Reno Car Manufactory uses 80 ton composite daily for buffer (2,000 to 3,000 daily), outer body such as backdoor fastener (1,500 daily), back ceiling folding board, as well as hanging components such as spring, torsion bar, valve cover under engine cover, crust of water pump crank shaft. By using composite, outer body has higher hit-energy absorption while the hollow due to hit is still comparable to metal. Buffer and side guard components can be made of SMC. In Europe it is popular to use same colour for the whole outer surface of car of smooth shape which is difficult for SMC.

So people have started to consider of using thermoplastic with cheap coating (polyacylide). Components made of polyaminester using RRIM technique are available in market. This indicates that great effort is needed fort large-stage application of composite to civil industry. Metal and plastic have been competing with composite. So we must innovate design combined by new manufacturing engineering to reduce its cost and enable it to overwhelm metal and plastic.

There are 3 papers at this meeting related to manufacturing engineering of short fibre composite for car use including methods of avoiding "welding seam" on pressed module, flow change of injection modul press, press technique of multipoint feeding for controlling fibre feeding direction. There are 6 papers about mechanical property and 4 from them talk about break mechanism of SMC material and the possibility of application of break mechanics as well as the study on break toughness, "crackle dispersion coefficients", etc. Other two papers discuss about fatigue and stress corrosion. The forementioned 12 papers about short fibre MMC and three papers about short fibre or crystalline bread CMC are also possible of being used in car engine though its cost is high and the technique is not so mature.

There are much more research projects of composite in car manufacture which, however, were not presented at this meeting.

1.3 Fibre developing status The modulus of heat-resistance composite fibre is surely higher.

1.3.1 Fibre made on filament lining base Boron fibre made of CVD on tungsten filament lining base has the modulus exceeding

400GPa and satisfactory compressive strength due to its large diameter of 140μm. However, complex process and very low productivity make it too much expensive for common use. There are more than 200 B/Al tubes in frame of US space aircraft. It does not promise any prospect of practical application so far.

The MMC made of silit fibre of CVD on tungsten or darbon filament lining base has modulus of 412GPa and it can withstand high temperature of 1,000°C. However, it is not applicable for practical use due to its high cost either.

1.3.2 Carbon fibre is appropriate for heat-resistance composite, but it has relatively low percentage elongation. So these years people have been trying to improve its elongation. Within this decade its percentage elongation has almost been doubled by going up from *1%* to *1.8%* and hopefully *it may reach 2.2% soon*. This was achieved mainly by improving its microstructure, raw filament quality and condition of thermal disintegration. Its diameter has been reduced to 5μm. The latent potentiality of further increasing its elongation is resin instead of fibre itself. Improving resin toughness will bring property of carbon fibre into full play.

Carbon fibre made of raw PAN filament costs too much to be applicable to civil industry. These years people have tried to make carbon fibre using asphalt -- the remainder of coal and from oil refinning. This reduced its cost but at the same time raised its processing cost. Sanling Chemical Company planned to make commercial fibre using asphalt from coal beginning at the end of 1987. The purpose is application to civil industry. Still, people can not expect to use any kind of carbon fibre in car manufacture within this century.

1.3.3 Ceramic fibre has short history of less than ten years. In 1979 Du Pont developed commercial ceramic fibre which is long fibre MMC made of pure α-aluminium oxide. It has high modulus but can not be woven due to fragility of large grain of α-aluminium oxide. It has the diameter of 15--20μm and it can withstand 1,000°C.

In this decade Japan Carbon Manufactory made Nicalon indicating a new turn of new-type ceramic fibre. It contains 70% of SiC and the rest constituents are silicon dioxide and free carbon atoms. It has the diameter of 12--15μm and it can withstand 1,000°C. Above this temperature Nicalon may creep and get oxidized. It is "transparent" to microwave radiation, so can also be used as function material.

Japan UBC Industrial Company has used the similar method to make Tyrano which contains titanium and is in amorphous structure. It is said to be able to withstand 1,300°C.

There are several more kinds of fibre made on the basis of aluminium oxide. The aluminium oxide fibre made by Japan Sumitomo has lower modulus but it is lighter and can be woven and can withstand 1,000°C. It may creep only at the temperature above 1,000°C. At the temperatures between 1000°C--1500°C it may have sudden phase transition causing the loss of its modulus and strengh.

SAFFIL aluminium oxide short fibre made by ICI was originally used as material for thermal insulation. Later, it was found to be useful in reinforcing metal. Its diameter is only 3μm. Recently a semicontinuous fibre named SAFIMAX has been made.

3M Company in US has made Nextel. In the coming years more and more new products will be added into the list of ceramic fibre. Nowadays fibre capable to withstand temperature above 1,200°C is highly desired because next generation of space aircrafts and space flighters have to work in this temperature region.

Other kinds of short ceramic fibre and crystalline beard can be used in reinforcing metal, but its developing is limited due to the high cost and lack of appropriate application. However, some new products have shown up recently. Besides, car manufacture requires reinforcing aluminium connecting rod in order to increase its stiffness. So the research on that is also active.

1.3.4 Organic fibre Nylon fibre has small modulus of 4--5 GPa while Polyester fibre and Nomex fibre have modulus of 17--18 GPa. They are useful in reinforcing rubber only. The organic fibre useful for composite material has been Kevlar 49. Recently Du Pont Company made Kevlar 149 with the modulus of 179GPa which is 40% higher than that of Kevlar 49 but the low hygroscopicity being 70% of Kevlar 49. However, Kelvar fibre is anosotropic. So it shows poor property along all directions except axial direction. It is well known for being not applicable to main components which has to withstand pressure. Technora fibre (HM-50 in old name) made by Japan Teijein also belongs to aromitic polyfibre. Also, It can be used in reinforcing rubber only due to low modulus. To make organic fibre with high modulus unitary polymer should be used. Make its molecular structure lining up unidirectionally when preparing it.

The modulus of this kind of organic fibre may reach 240GPa. Dutch DSM Company has made polyethylene fibre of high modulus which can compete with Du Pont's Kevlar. Its specific gravity is only 0.97. However, it can withstand the temperature of 120°C only and beyond that its creep is serious. So it is currently used for sport equipments only.

The majority of fibre property has been discussed in papers related to mechanical property of composite at this meeting. For example, ceramic fibre in fastest developing is mentioned in papers about CMC and MMC. There is only one paper discussing about Polyethylene fibre of high modulus. British Columbia University of Canada has tried to investigate the possibility of applying it to force-bearing components in the form of mixed fibre. It has been found to have relative large hit-energy absorption rate through tests of bending, layer shearing and falling-tag hitting. However, its interlayer shear strength is very low resulting in layer-off. At bending the specific gravity of carbon fibre can be increased to enhance its stiffness, but its percentage elongality gets very low. The author recommends appropriate adjusting the ratio of Polyethylene to carbon fibre and laying order of layers in order to obtain satisfactory layers.

1.4 Polymer basegroup developing status The use of polymer basegroup was the earlist one from three basegroups (polymer, metal and ceramic). Recently people have asked for its improvement most eagerly. The age of epoxy resin is over 20 years and it has been used in most of force-bearing components. It has had relatively complete data storage and various specifications.

Unfortunately, it is too fragile, it has too long solidification time and too low working temperature and its cost is still rather high. Therefore, the development of polymer basegroup is mainly towards these problems.

There are 4 papers in the group with the subject of polymer basegroup. Phillips Petrolium Company in US recommends polyaromatic sulphide (PAS) as thermoplastic basegroup of high quality which has excellent chemical reaction resistance, thermal equilibrium, high strength, satisfactory fireproof and good property for process. With glass fibre, carbon fibre, aromatic polyfibre, it can be made in the form as fabric or continuous fibre for preparing presoaking ribbon. The second paper talks about application of composite to dentistry which discusses as how to determine the extent of transformation of single molecule into polymer for dentistry using thermal analysis and what is the proportionality of inorganic stuffing in organic polymer basegroup. The subject of the third paper is "The structure and elasticity property of the triple composite polypropylene/high elastomer/stuffing" by two authors from Czechoslovakia and Hungary which is actually the continuation of previous work. Its background is that PP (polypropylene) has very poor hit resistance under Tg (-10°C), however, mixed with high elastomer EPR by 5-20%, its hit resistance is improved significantly because at hit high elastomer produces concentrated stress causing microcrackle and plastic deformation making PP absorb energy thus avoiding macroscopic damage. However, high elastomer reduces yield point of stiffness and creep resistance of PP, so stuffing (calcium carbonate) has been added to it. The purpose of this paper is to determine control factor of phase structure by SEM observation after hitting it by free vibrating torsion pendulum. The fourth paper is related to composite of Geopolymer basegroup which can withstand very high temperature (1,200°C).

More research on polymer basegroup is reported in papers about relevant composite property which cover almost all the polymer basegroups of practical usage, such as thermosetting BMI phenolic aldehyde, polyetherimide and thermoplastic PEEK, polycarbonate, PPS, PSP, PEI, PES, fluoroplastic (FEP, PFA), etc. Instead of introducing all of them, I will mention about the most important information in the following text after sorting them out:

The advantage of PEEK over epoxy has been well known, but it has its advantage as well as disadvantage in solidification process. The advantage is fast processing and long deposit time. However, thermoplastic composite needs thermal formation. Some process such as hot-head winding is only in laboratory stage, any method requires high temperature (350-370°C) and high pressure. Thermoplastic composite is said to cost less, but nowadays the price of thermosetting basegroup is US$ 20-40/lb, high temperature thermosetting basegroup (BMI) presoaking ribbon costs US$ 65-75/lb, while thermoplastic basegroup costs US$ 80-100/lb. Besides, a complete data storage is required in actual use of thermoplastic basegroup. Having been used for over 20 years, epoxy resin still may show some unexpected problem, for example, after hit by a hard body the single layerbase at pressed side on carbon/epoxy layer may get bend which is unexpected. It is said that thermoplastic basegroup has better toughness than that of thermosetting basegroup, but it is more sensitive to gap. Thermosetting basegroup has microcrackle at hole edge which relaxing stress concentrating, while thermoplastic basegroup does not have microcrackle so it is easily to get broken. Nowadays thermoplastic basegroup is still unable to be used as force-bearing components, it also need accumulate data of environment resistance for a long period. However, it is an appropriate material for components usually suffering from scrapping such as flap, front-edge slats, front and back of control surface and door of landing gear because it is easy to be repaired or replaced. The most prospective thermoplastic is three types appraised for Wright-Patterson by Lockheed: APC/HTX of ICI (a type of PEEK), PAS-2 by Phillips Petrolium Company (a type of Polyarylene Sulfide) and PSM 8505 by Amoco Company (polyacrylic ether sulphone). There are two more types of non-thermoplastic material which can also be used: Torlon AIZ 638 by Amoco Company (polyimide) and Aramid III by Du Pont (a type of polyimide). Besides, there is a liquid-crystal polymer, Xydar by Dartco (a type of self-reinforced plastic) which is made by BASF in Germany and is similar to thermoplastic PEEK, also LARC-TP1 made in Japan which is a type of thermosetting polyimide discovered by NASA-Langley.

The most prospective successor of thermosetting basegroup which can be used for force-bearing components is polyimide. The type of polyimide may depend on working temperature. At 350-370°C LARC-TP1 and PMR-15 get solidified and it can be used at higher temperature. However, at mixing raw constituents, chemical reaction makes volatimatter form gas hole thus making material property worse. Using synthetic polyimide can solve this problem because original raw constituents have gone upon forming final polyamide so it does not make gase hole. However, its working temperature gets down. BMI is the most prospective synthetic polyamide and the same type of equipment set for epoxy solidification fits it perfectly with only little change needed in solidification technique. Unfortunately, BMI also has its disadvantage, that is, its moisture absorption speed is 10 times of that of epoxy though the total amount of moisture absorption is not much.

1.5 Fibre/basegroup boundary Fibre/basegroup boundary is said to be the "heart" of composite material. Force is delivered by the boundary between fibre 'basegroup so that constituent material can become composite material. The majority of the papers are related to boundary problem to more or less extent. However, so far people are still not clear with the boundary problem, there are many phenomena being contradictory and are difficult to be explained. They can not be associated to macroscopic property, especially chemical reactions at boundary can not be observed and measured, so much work remain to be done in either theoretical analysis or experimental technique.

There are 6 papers with the subject of fibre/basegroup boundary at this meeting. The first one reports study on boundary using some modern test technique by F. R. Jones et al in England which includes XPS method (X-ray Photoelectron Spectroscopic Analysis) which observed chemical and microhollow structure on boundary. It is known that surface oxidizing enhances sticking of carbon/epoxy boundary, but contradictory report has been coming out, so they did quantative analysis of acid concentration at boundary using XPS barium tracer method and they furthermore determined epoxy absorption by microholes. In order to relate chemical and microhollow structure to mechanical property, they used SIMS (Secondary Ion Mass Spectrometry) to analyze transverse break surface to check the existance of very thin basegroup layer retaining in fibre surface layer, they observed change and characteristic of boundary structure and break surface by changing surface oxidization process of fibre. Their result cleared ambiguous concept from previous research and verified the conclusion of improvement of sticking due to surface oxidization.

The second paper is by Bascom et al in US which observed an *unexplainable phenomenon: AS4 and AS1* fibre has poor sticking with thermoplastic basegroup while carbon fibre XAS shows excellent boundary sticking with the same type of thermoplastic basegroup. The authors tried to improve sticking using surface processor and heat cleaning with no success. The surface analysis of AS4 and XAS by surface spectroscopy and soaking measurement could not find the reason of causing such difference either.

The third paper is by Barlow in England discussing the role of boundary sticking in property of thermoplastic reinforced by continuous carbon fibre. It proved that boundary strength can be stronger than fibre and stronger than basegroup at the best case.

The fourth paper is by Sawada et al in Japan trying to explain some contradictory phenomena. They obtained definite linear relationship by taking active surface area and surface roughness of fibre as the parameters and relating them to macroscopic shear strength.

The fifth paper is by Verbruggen in Holland. He concludes from test that break of either type I or type II reduces its energy release because degumming reduces stress concentration and supplies more energy consum mechanism such as fibre get off. However, degumming is harmful for compression.

The sixth paper is by Jacques et all in France who determined shear strength at boundary using redesigned Fraser-DiBenedetto monofilament test.

1.6 Development of manufacturing engineering of composite

Many research achivements in manufacturing engineering have been reported in many papers, especially those of CMC and MMC which have been mentioned above. There are 14 papers are grouped with the subject of manufacturing engineering from which the problem of welding seam on pressed modul of SMC: flow change of composite reinforced by injection modul pressed long fibre and controlling fibre flow direction by multipoint feeding have been mentioned above.

An important problem is as when to press in solidification process. For that need to monitor parameters in solidification process. Wetton et al in England and Kranbuchl et al of VPI in US recommend association of chemistry in solidification process with dielectric property of polymer by dielectric analysis to get more accurate characteristics of solidification process.

Ridgard in England discusses about advantage of manufacturing engineering of components or tools used at high temperature from presoaking ribbon modul pressed at low temperature.

Large-scaled production requires high quality of surface of solidified component, especially something like components of outer side of cars which surface quality has to compete with that of traditional metal components. Spiro et al in Germany discussed about tools, especially the requirements of tools formed by electrocasting.

Ma Zhenji et al of Taiwan Qinghua University discuss about the influence of technical parameters of steel glass and carbon/epoxy sports instruments made by drawing process which attracted audience attention.

Li Xiangli et al of Wuhan Institute of Technology in our country proposed non-shorthaul winding equation on any gyration camber. Welis in England recommended making winding software supplementary to computer by non-shorthaul linear locus.

Brito in Portugal is concerned about the difference between winding and laying boardcrust. When he took column crust as an example to study its stiffness coefficient, he found that stiffness coefficient gets stable with increase of number of winding layer and the stiffness matrix approaches symmetric. However, if winding angle is small, this result can not be obtained.

Crivelli and Visconti in Italy studied about the quality criteria of mechanical process of fibre-reinforced composite using laser beam and the influence of cutting parameters on quality. Their result shows that cutting speed and energy distribution of laser beam turn to be two main factors.

New type of composite process includes rapid developing technique in knitting, weaving, etc which, however, no special papers report about that at this meeting.

1.7 Damageless flaw detection There are 12 papers grouped with the subject of damageless flaw detection. From them 5 papers are related to the application of sound radiation technique from which 4 papers are talk about the application of sound radiation technique at bending, monitoring break of CFRP and SMC and blue measurement of layer-off of composite reinforced by carbon, aromatic polyfibre and glass fibre. Cherfaoui et al in France proposed a method for sound radiation data processing which is actually the continuation of previous research. First they made AE signal numeric, then determined frequency spectrum, finally obtained more information from the data after using multivariable data analysis and automatic categoring technique. The authors beleive that this method will become more and more advantageous with improvement of instrumentation.

There is a paper by Rief et al in Germany discussing about analytical technique of photothermal wave. The authors think of this method to fit CFRP very well because these materials have high light absorption and thermal conductivity therefore can obtain measured data of higher accuracy. Thermal field is produced by photo radiation then data for thermal wave is obtained. It has definite relationship with fibre modulus and the accuracy of measured fibre volume ratio may reach 1%. Crackle, gas hole and inclusion may be detected at the depth of 0.12mm. This method can also be used for monitoring solidification process.

Schulte et al in Germany did immediate measurement of temperature increase of composite under circulatory load using thermocouple. The authors beleive that thermal phasemeter can not describe the true evolution process of fatigue damage. According to change of thermal conductivity coefficient of materials around damage region they used temeprature change to represent the accumulation of damage and obtained the result which is consistent with those from other methods.

Thierf in France examined gase hole layer off and inclusion using medical X-ray layergraphic densitometer which can also be used to observe revolution of deficiency effected by humidity and temeprature, etc. The author beleive that it can successfully compete with some other damageless flaw detection methods. It is especially useful for thick material.

Summerscales in England used Raman effect, the scattering of light in going through material, that is the effect of random change of its frequency and phase. This kind of scattering can be easily distinguished from Rayleigh and Tyndell scattering. Raman scattering can be analyzed by spectrometer. Laser is the ideal light source of Raman spectrometer. This paper summarizes the application of Raman spectrometer to composite material.

Robinson et al of England measured stress of composite fibre using Raman spectrometer. For that they used crystal fibre, polybutalkadiynes, as a opticomechanical stressmeter which is buried inside transparent basegroup. This paper did quantative measurement of stress concentration at crackle endpoint.

Cawley in England recommends determination of deficiency of honeycomb splint using "coin" knock which actually uses handhammer with a forcemeter instead of coin. Recording history of knock force and analyzing its frequency spectrum using FFT, comparing records of deficiency and result of frequency spectrum analysis with record at deficiencyless region and its analysis result will detect deficiency. This paper shows the confidency in detection of deficiency with diameter of 10mm under surface with the thickness of 1mm. It is more sensitive than trouble diagnostic of mechanical impedence is.

1.8 Mechanical characteristic and property of material At this meeting the papers related to this topic are the following by statistics:

12 for mechanical characteristic, 11 for hit property, 8 for flaw mechanism, 29 for break, 13 for fatigue, 8 for long term strength, 6 for creep and sticking property, 4 for thermal flaw and corrosion, 5 for thermal effect, 7 for friction. Total 103 papers. From which 16 are in microscopic mechanics, 21 are related to constituent material using new technique and 16 are from factories and research institutes.

Mechanical characteristic There are two papers related to stretch test of mixed fibre composite. Lots of research in this area are going on and many tests have been reported, however, these two papers are characteristic of non-unidirectional fibre. Aiming to glass/carbon/epoxy [0°/±45°/90°], Emperial Science and Engineering Institute of England studied the influence of glass fibre volume ratio and obtained its nonlinear stress strain relationship using finite element calculation. Shen Bixia et al in Shanghai Glass Institute in our country found the method of mixture law for foretelling stretch and bending modulus by stretch test using carbon/glass cloth/epoxy, and they determined the volume of carbon fibre with its minimum strength being equivalent to the strength of pure glass cloth.

According to smaller plasticity of composite along fibre direction thus retaining only one parameter in plasticity potential, Sun Jinde et al in Purdue University in US finally obtained the general nonlinear stress strain relationship of orthogonal different-natured composite and they proved it using boron/aluminum and graphite/epoxy layer.

Compression property of composite has been a problem calling people's attention. T. Hahn in US analyzed formation law of fold bend under compression, described kinematical law of fold formation using deformation tensor and finally related pressure to fibre deformation using equilibrium equation. The strain of shear damage of basegroup was obtained by combining test with analysis which clarified mechanism of compression damage and indicated parameters controlling compression strength.

Lee et al in England did compression test of unidirectional carbon/thermoplastic and compared that with the result of epoxy basis. They beleive that strength of PEEK group composite declines significantly after raising of humidity. A paper by Soviet Union says that test result may be significantly influenced by manufacturing engineering and test condition. One thing being common with Hahn is recommendation of using basegroup material of high strength and high stiffness in order to enhance compression strength though this may reduce its stretch strength a little.

There are two other papers discussing foretelling model of stiffness of random-directional short fibre composite and mechanical property of semicrystal thermoplastic composite at high temperature.

Hit Referring to hit there are two papers related to study of energy absorption of composite structure at hit which discuss the influence on energy absorption of structural form, geometrical shape, and some other parameters. Its application background is how to increase energy absorption in hit accident of plane or car in order to guarantee the safety of human being. Besides, there are falling-tag hit, bullet hit, Hopkinson rod hit, the relationship between pendulum hammer hit and Hopkinson rod hit as well as hit peeling along thickness direction of thermosetting resingroup and thermoplastic resin composite by using blasting foil. Another paper talks about effect after gummembrane lining in order to reduce layer-off due to hit. Most of the papers about low-speed hit mention problem of layer-off. Still, many questions about hit damage remain unanswered due to the difficulty in experimental observation and measurement of relevant parameters.

Flaw mechanism A paper related to flaw mechanism written by Xue Yuande in Tongji University in our country analyzed flaw mechanism causing transverse crackle, edge layer-off and fibre break and it concludes that boundary degumming happens earlier than basegroup break does based on finite element analysis. The normal stress between layers of 0° and 90° ($[0/90]_S$ and

$[0/90/0/90]_S$) is greater than the normal stress between the central 90° layers. They also did analysis of stress at section of longitudinal fibre. With the appearance of branch crackles and extension of flaw area, the longitudinal stress at fibre section gets reduced first, it then approaches a stable value. Takao in Japan discusses influence of shear strength at fibre section on flaw extension. Goree in US discusses influence of gummembrane lining on flaw extention. Jamison in US furthermore discusses influence of fibre break in making worse and damaging the property of composite.

Break The study on composite break is mainly towards three directions: (1) layer-off, (2) basegroup crackle and (3) macroscopic break. From which layer-off study is the most active one because layer-off is the most commonly observed break form under static load, hit and environmental influence also because the problem of layer-off break is least difficult to be solved. There are totally 29 papers about break at this meeting from which 11 papers talk about layer-off which include observation of characteristic of type I and type II break as well as behavior of type III break. There is also study of mixed layer-off which includes effects of nonlinear, temperature, strain rate and humidity under compression. Two papers talk about test from which one discusses effect of large displacement of DCB testee while another paper discusses influence of remnant stress on layer-off at testee edge.

There is one paper comparing flaw region with stress field at frontend of layer-off in type I and type II. The author considers one to one correspondence between them. Zhang Hang in Beijing

Aeronautics Institute in our country calculated strength factors of type III stress using analytical method.

There are two papers studying basegroup crackle from which one is by Kelly et al in England which discusses a problem: which problem should be used as the break criteria of elastic crackle and constrain crackle: stress strength factor or energy equilibrium principle. In addition to summary, the paper investigates break mechanism a little.

The main problem in macroscopic break of composite is whether break mechanics may become applicable or how which covers break problem of composite with elliptic hole edge crackle, mixed-type, shortcut fibre and PEEK group, glass cloth/epoxy and graphite/epoxy by Yang Bingxian in Beijing Aeronautics Institute in our country, three-dimensional column-shaped and torsial column crust. Some people discuss influence of anisotropic elasticity and plasticity. There is one paper by Xiao Wanchun et al in Westsouthern Petrolium Institute in our country which calculates size factor in anisotropic plastic region.

Fatigue The paper named "Direction and deviation of life foretelling" by Riefsnider is one of the nine conference lectures at this meeting. The author made a rather general investigation at the philosophical level which is actually out of the range of fatigue. At his conclusion he said: (1) For the future damage to be foretold must understand thoroughly every detail of physics, chemistry, mechanics, etc, (2) must select properly the geometrical size of the problem, include into analytical model the factors which is important for damage and average the least important ones to make the model practical, (3) must include self information relevant to both characteristic and damage evolution, such information must be based on experimental observation and understanding firmly, (4) analysis of local stress status must match the damage status of the whole material.

He recommends the combination of continuous medium with dispersion model.

Five papers from the total thirteen talks about establishing model which includes establishing model of flaw extension from bending fatigue test, characteristic of torsion fatigue, relating stiffness reducing to different kinds of flaw extension, model analysis of environmental influence, etc. The other five papers report fatigue behavior of new material, such as fatigue behavior of improved carbon fibre composite, composite of toughness-reinforced basegroup, thermoplastic basegroup composite, fabric, mixed fibre composite, etc.

Long-term strength This is an important problem in application of composite to industry, especially aerospace industry. It takes quite long time to study on that. There are 6 papers related to lont-term strength caused by water absorption and hygrothermal aging, as well as influence of water on layer-off fatigue. Besides, there are tests on hygrothermal aging of PSP and accelerating aging, etc. All of these papers report research projects in universities. Actual work going on is more than that reported in these papers, but that work is mostly the data gathered by industry and research institutes without systematic arrangement simply in order to meet the product demands.

Creep and sticking Creep and sticking must be taken into account in studying the property of basegroup-dependent composite. Six papers in this area include research reports on creep of random directional shortcut fibre composite, resingroup composite torsional thin tube, creep of hygrothermal-influenced composite. Accuracy in measurement may be effected in case instrumental components and support of optical equipments are permanently deformed to the extent of 10^{-7}-10^{-4}m/m. There is one paper discussing deformation due to microscopic yield bending of sticking basegroup composite. Another paper talks about the research on reduction of fabric strength after creeping.

Thermal flaw and corrosion There are four papers discussing about thermal fatigue of unidirectional reinforced graphite/resin layer, stress corrosion and break of Nylon 66 shortfibre composite. Finally, there is one paper determining denaturing caused by corrosion using acousto-ultrasonic technique. The so-called acousto-ultrasonic technique is the combination of two damageless flaw detection methods: sound emission and ultrasonic technique. An ultrasonic pulser inputs dispersed ultrasonic pulses to testee material. Its output wave should be the modulated signals of characteristic material due to the existance of microstructural difference inside material and the wave is picked up by sound-emission sensor. The picked wave is transformed into numerical signal as the characteristic symbol of material flaw, such a number is generally called stress wave factor. This paper characterizes material denaturing by adding GRP into acid and using acousto-ultrasonic technique.

Thermal effect Solidifying tests have been done at different cooling speed for PEEK and carbon fibre reinforced PEEK composite. It was observed that slow cooling may increase crystalline extent resulting in lowering its toughness. Cooling composite at speeds of 19°C/min, 3°C/min and 1°C/min, the result shows significant difference between property of composite cooled at speeds of 3°C/min and 1°C/min. Layer-off resistance of slower cooling composite gets lowered significantly. From the total five papers two papers are written by authors in our country: Zhao Jiaqiang et al in Space Navigation Administration measured thermal conductivity coefficients and thermal expansion coefficients of 3D C-C at room temperature and 2,000°C respectively and they analyzed thermal vibration-resistance of 3D C-C from thermal vibration-resistant parameters. Song Huanchen et al in Beijin Aeronautics Institute did experiment in studying layer residual strain and stress due to solidification.

Friction From the total 7 papers one is the summary, another discusses mechanics and friction property of SiC crystalline beard/silicon-nitride about which little work has been done so far. Previous reported work on composite friction is mostly for resingroup composite which includes friction behavior of continuous fibre composite, influence of Gr/Ep fibre direction on friction and friciton-fatigue property of carbon fibre reinforced layer. There is one paper related to composite friction process discussing experimental method of characterizing Kevlar fibre surface, the so-called contrary gas chromatograph technique. This method measures thermodynamical information of gas absorption by fibre surface in order to obtain the relevant data of chemical action at fibre surface.

1.9 Data storage Following is the main contents of Lockett in National Physics Laboratory of England at the conference:

Nowadays different material traders supply material with great difference in data, so users must be very cautious to prevent from error. Generally speaking, the data available currently is far from enough. Sometimes one component is produced immediately from mould pressing constituent material. In such a case it needs to foretell stiffness and strength of components from the behavior of constituent material.

The source of material property data is miscellaneous, some are from material traders, others are from laboratories, institutes and users themselves. They also use diverse test methods. Such status must be changed in order to use composite realistically and scientifically.

1.9.1 Different technique differs in requirements so different data is needed:

Characteristic property of material, such as sticking and elasticity (influence of time and strain rate frequency); nonlinearity (physical or geometrical nonlinearity); anisotropy (orthogonal anisotropy, transverse isotropy, etc); non-uniformity (composite structure such as lining); random.

Deformation load mode: stretch, bending, shear, compression, two-directional stress status, etc.

Material behavior: short-term strength and stiffness, creep deformation and damage, dynamical stiffness and loss, fatigue, hit toughness.

Environmental influence: temperature-related property, property deterioration due to aging, coupling between mechanical force and environment. Users should make clear as which data he needs to establish relevant mechanism for standardization.

1.9.2 Usage of material data

Initial selection of material, processing and preparing material, product design. Property data is just one factor having to be concerned about at the initial selection of material. Besides that, cost, process property, design capability, investing, etc have to be considered. Product design requires more specific, accurate and wide data.

1.9.3 Determination of data to meet the real needs according to the specific requirements of product.

This may depend on quality requirements of product, for example, aerospace product usually requires more comprehension and higher accuracy while boat for sports use is different without the necessity of considering nonlinearity and non-uniformity of its shortcut fibre composite. It is very important to find out which formula are needed in product design and which data is input from CAD. Generally, there is no real need in large amount of data. One thing worthy attention is the needs in gathering data of material property for specific component material in specific manufacturing engineering because being different from metal, the equipments and system for solidification of composite may effect final property of the material.

1.9.4 Gathering data

Measure immediately, deduct result from immediate measurement, calculate data.

It is a mature method of calculating data of composite property according to data of constituent material or calculating layer stiffness data from the data of single layerbase stiffness. However, the calculated result can be taken as the approximate data due to decentralization of material property. The so-called deduction from immediate measurement means the method in obtaining unpretested data using interpolation or extrapolation following some certain law. Data processing using addition method and acceleration test also belongs to this type. The most reliable data is that from immediate measurement, but current data is lack of necessary explanation, for example, the test condition in gathering data should be described. However, the most fundamental method is to standardize test method.

1.9.5 Standardization of test methods

It may save effort significantly by using test standards of metal or hard plastic. In fact hard plastic contains stuffing. ISO experiment of hard plastic can certainly be used as the standard test method for composite of shortcut fibre from injection module pressing or grain-reinforced composite. However, it is necessary to reconsider test standardization of continuous fibre-reinforced composite due to its anisotropy. Table 2 shows some given test standards. Many important test standards are not available, such as creep and hit. Fatigue also does not have the standard test method for bending. The material I mention here is unidirectionally reinforced composite instead of other laying composite. CRAG (Composite Research Administration Group of the Ministry of National Defence of England) suggests immediate using short-term test method listed in Table 2 as the standard test method for creep and fatigue. Standard test method for layer-off is on the way to be work out.

Table 2 Standard test of resinbroup composite

property	ISO	ASTM	BSI	DIN
stretch(short term)	3268	D3039	2782/320E,F	EN61
bend(short term)	3597	D790	2782/1003 2782/1004	EN63
compress(short term)	3605	D3410	–	–
shear (short term)	–	D2344 D3846	2782/341A	53463
fatigue(stretch)		D3479	–	–

1.9.6 Standardization

Standardization includes: name and categoring standardization, method standardization, standardization of technical requirements (material, process, etc), symbol standardization. Nowadays different countries have different standards, and even different units in a same country may use different standards. So the problem is the consistency between current standards. The data-supply format should also be standardized, such as data ordering. Certain description should be attached to inform users as how to select test parameters, etc. In order to enhance the data reliability, an authoritative mechanism for instrumental demarcate and test accreditation should be established. England has NAMAS (National Measurement Accreditation Service) and NATLAS (National testing Laboratory Accreditation Scheme). There are three papers discussing about test standardization at this meeting. The paper named "Current status of composite mechanical test" by Soviet Union indicates the current lack of a satisfactory test standard for shear test. US Du Pont Company proposes a method for testee design, making and test for Kevlar fibre-reinforced composite test (stretch, shear, bending). They think that the current standard should become flexible due to the anisotropy of Kelvar fibre and some characteristic in cutting process of its test components. The paper with the subject of "Comparison of the standard test on carbon/epoxy" by US Delaware University and England Emperical Institute of Technology shows significant statistical difference between measuremental result by using different test standard method.

1.10 Structural analysis and interlayer stress.

There are totally 18 papers for structural analysis from them 6 papers talk about crooking, three about vibration, other papers about open crust, board bending due to load blasting, etc.

Five papers (excluding those written by Chinese abroad) are by Chinese authors. They are: Beck type load-bearing layer column stabilization by Mr. Wang Junkui et al; several problem in stabilization analysis of composite tube crust by professor Zhou Chengzhou, frequency and vibration analysis of wing-shape structure and its relevant optimum design by Liu Sheng; contact stress analysis of the mechanical connection of composite by Yang Ling et al; infinite element analysis and design of 25 MW generator protection ring using eight-node parameter unit.

There are six papers discussing about interlayer stress from which three are for stress calculation. They are: three-dimensional finite element analysis of corner-laying layer with circular hole under compression, another is about simplified calculation of interlayer stress around circular hole on corner- laying layer. There is one paper analyzing interlayer strain and stress using Moire stripe. Another paper analyzes action of gummembrane in facilitating interlayer change and controlling edge layer-off. Also study on layer-off spreading and final inefficacy by Lagace in US. The final paper is by Zhang Ruguang in Shanghai Glass Institute discussing the criteria of composite damage controlled by basegroup and interface.

There are 18 papers from the total 24 discussing about calculation from which 15 use finite element method.

2. Several Important Problem of Composite in Our Country

The developing of steel glass material in our country starts not so late, but the developing of advanced material of composite falls well behind other developed countries due to various reasons.

In order to catch up other countries in the development of advanced technique, we are faced with the problem of developing heat resistance composite. Our country has imported and are in the current talks with foreign countries about importing several production systems of SMC and shortcut fibre composite though some problems exist related to digesting these materials in civil industry, large-stage production and cost reduction. It is necessary to develop variety of ordinary (<150°C) resingroup composite, improve its quality, understand it more, use it reasonably in order to catch up developed countries.

Nowadays fibre and basegroup used for preparing heat resistance composite (either thermosetting, thermoplastic resin, metal group or ceramic group) are "prestudied" unhurriedly because it is not of great demand by industry. Some of them are developing fast, such as silicon carbonate fibre, while some are slow. Some steel glass products have been used as composite in civil industry, while the application of shortcut fibre composite (such as window frame of train carriage) has just started. Its developing tendency is not significant due to its high cost.

Material industry seems to need an overall plans and take all factors into arrangement, user departments should suggest criteria of qualified products, university, research institutes, design-manufacturing departments should divide the total work for each to carry on at the same time cooperate well with each other thus avoiding concentrating on one part. Avoid repetition at low level, assign specialists responsible for the development at every branch and emphasize supporting important items.

Nowadays the development of ceramic group composite abroad seems to be faster than that of metal group composite in the tendency of catching up and surpassing the latter. Before ceramic material in our industry is mostly used as function material while little study on heatproof structure material, the advanced application to industry. It is not much difficult to correct it. Based on the source in our country, it needs to enhance cooperation and coordination between all units for rapid development of composite. Rules and regulations seem to hurt the crosswise cooperation between units.

Besides material, developing new technique is extremely urgent. Some technique in our country has become more experienced such as winding technique by Harbin Glass Institute. In these years much new technique has shown up, such as knitting, weaving, etc which also need to assign people to study on and develop soft small-diametered fibre fit new technique. Surface process is also of great importance. There exists the problem of crossing and coordination in the development of material and technique. Much new information about technique of preparing metal group and ceramic group composite requires research.

Our country has put much human efforts into study on composite property. The standardization problem has to be solved. There is no harm to start at the standardization set by foreign countries, work carefully in each stage, advance step by step, be steady and sure, accumulate all true and useful research result and data, avoid extravagance during investigating and preparing composite.

The key in developing composite is human source. Qualified people are desired to work in various division. For that must emphasize on training. We need not only researchers at high level, but also large amount of people at medium level. This is extremely important in large-stage of manufacturing composite products. Should support and direct current composite products for civil use and make it the real property with high technical concentration.

Great effort from universities has been put into composite development. The current problem is how to match practical needs. So material science, mechanics and applied science need to merge with each other. Because composite is the newly developed material which requires highly the combination of different majors in science, everybody should try to go out from his old major, see well the complete view of composite, give his play into aciton. Besides, leadership should support composite financially for its success. Composite is rather expensive so test is necessary during its development. Currently most testing equipments in universities are very poor. Though it is not possible to improve all those equipments due to the source available in our country, we should choose some prospective universities as the key units and support them strongly so that they can make more contribution to composite development in our country.

We are confident in catching up provided we bring into play the advantage of socialism system in our country, organize available source and pick up our speed.

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